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INFRA-RED PHOTOGRAPHY.

By Keivin Burns.

Until the end of the eighteenth century the known spectrum embraced the visible part only. Between the limits 3600 A and 7600 A, or a little more than an octave, the spectrum may be studied by visual methods. These limits, of course, apply only in case of the average eye and for a spectrum which is intense at the given positions. The opening year of the nineteenth century marks the discovery by Herschel of the region of wave-lengths greater than that of the red. This observer was able by meaus of a delicate thermometer to study the distribution of energy in the solar spectrum, and he discovered solar rays of wave-length at least twice as great as any already known. Almost at the same time Ritter, studying the effect of light on silver chloride found the ultra-violet rays. Since the development of photography, especially since the introduction of the dry plate, spectroscopic studies of the region to which the film is sensitive have been carried on almost entirely by the photographic method.

This region until 1873 extended roughly from 1800 A to 5000 A. The discovery, by H. W. Vogel, that dyed plates become sensitive to the green, yellow, and red increased the scope of photography greatly. And since 1893 the method of Schumann has made it possible to photograph spectral lines of the shortest wave-length to which any known solid substance is transparent, and 1000 A has been reached. In the meantime Captain Abney discovered a method of preparing photographic plates sensitive to light of very great wave-length and was able to photograph the solar spectrum nearly as far as 20,000 A. He found it difficult, however, to get accurate wave-lengths for even the most intense metallic lines of wave-length greater than 8000 A in the terrestrial spectra; and up to the present no one else has succeeded in obtaining any results from this emulsion. Another method of photographing the infra-red spectrum depends on the fact that light of long wave-length quenches the phosphorescence of zinc sulphate. By utilizing this property of infra-red rays, BECQUEREL and later LOMMEL photographed the solar spectrum and obtained some results in the case of the spectra of metals. But until quite recently our knowledge of wave-lengths greater than 7000 A has rested mainly on work done with the bolometer, first used by LANGLEY in 1885 to map the solar spectrum to 180,000 A. The greatest wave-length reached by bolometric or similar methods is about 600,000 A.

The method of preparing photographic plates sensitive to the green, yellow, and red consists in staining ordinary photographic plates with dyes. Some of those which have been used most successfully are homocol, pinaverdol, pinacyanol, cyanin, alizarine, and dicyanin. The greatest wave-length obtained by the staining process has been reached by HERMANN in the spectrum of magnesium.[1] The limit reached was 9224 A and the dye used was cyanin. This dye is more troublesome to use than most of the others, as it has to be prepared by the investigator himself.

In the course of photographing the iron spectrum last winter, it was found that plates stained with dicyanin, pinaverdol, and pinacyanol enable one to photograph lines to 8800 A, using a 6.5^{m} focus grating in the first order. This led to an investigation of the limit of the sensitiveness of such plates. For this purpose a meter focus-grating was used, and films instead of plates were dyed. In spite of the fact that the dyed films were only very slightly sensitive in the infra-red as compared to the plates, the limit 9150 A was reached in some spectra. No lines which had not been photographed with the big grating were obtained in the iron spectrum, however. Dr. CHAS. F. MEYER, who took up the investigation of the infra-red with the small grating, very kindly allows me to say that it will be possible to obtain with high dispersion the spectrum as far as 9000 A of every element he tried. In all cases he obtained lines of wave-length greater than 7000 A, which have never been obtained before on account of their faintness, and in all cases save one he got lines of greater wave-length than any ever photographed before in the spectrum concerned. Dr.

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[1] Dr. MEYER did not photograph this spectrum. He was able to reach wave-lengths greater than those recorded by HERMANN in other spectra, however.

MEYER finds that the bands are often the most striking and interesting feature of the infra-red spectrum; their intensity as compared to that of the line spectrum seems in general to increase with increasing wave-length, as is the case with the iron spectrum. From the results obtained by Dr. MEYER and myself it would appear that the best dyes for sensitizing plates to the infra-red are those we used; dicyanin alone is perhaps the best sensitizer for the region beyond 8000 A.

The investigation of the infra-red is carried on mainly by the use of gratings, and this is so for various reasons. First, it is obvious that the construction of an achromatic lens for this region is more difficult than in case of the visual or ordinary photographic region. Then the dispersion of all available substances is very small in the infra-red and more prisms must be used in order to get dispersion comparable to that obtained in ordinary prismatic spectrographs. It is no mean advantages in using the concave grating to be able to adjust the whole apparatus by means of the visible spectrum. When this instrument is in adjustment for the visual spectrum, no other adjustment is necessary for any wave-length whatever. This is never the case with a prismatic spectroscope. Furthermore, the determination of wave-lengths by prismatic methods is difficult, and no great accuracy is to be obtained; while in the case of the grating the spectra of the otherwise unwelcome higher orders provide accurate standards.

These overlapping higher orders are bothersome in the extreme. In the case of bolometric work on line spectra the higher orders interfere but little, for there are but few lines of short wave-length whose energy is sufficient to affect the bolometer and their positions are accurately known. Captain ABNEY was fortunate in that his emulsion was not very sensitive to the green. In this case a good piece of red glass reduces the intensity of the second order sufficiently to allow 11,000 A to be photographed free from light of shorter wave-length. In working with the small grating here, and using films, the second order green was over-exposed in one second, while it was necessary to expose the first order of double wave-length for three and one-half hours. This great relative intensity of the green made the use of very dense filters necessary. It was found that all filters, which were investigated, transmitted the green to some extent and all reduced the intensity of the extreme red by at least forty per cent. In order to make sure that the filter was not the main cause of the spectrum's photographic limit, a simple prismatic filter was devised.

In order to secure the best results in using this filter, it must be adapted to the spectrograph with which it is to be used. The form in which it was used here is described in some detail. The light from the arc passes through a slit three millimeters wide. This slit would be unnecessary if the source were narrow and steady. A lens of eighty centimeters focal length makes the light parallel, after which a beam fifteen millimeters wide is allowed to pass through a thirty-degree prism. At a distance of two meters from this prism that part of the spectrum which is to be used passes through a diaphragm and falls upon the second prism. This second prism is exactly similar to the first, but its refracting edge is rotated 180° with respect to that of the other prism. In this way the light after leaving the second prism is parallel and the direction of the beam has been unchanged. Finally a lens of ten centimeters focal length throws an image of the above-mentioned slit upon the slit of the spectrograph. This filter permits any desired region of the spectrum to be studied by means of a grating, without the spectra of either higher or lower orders. There must always be a small amount of diffuse light, but this is easily reduced to a harmless intensity by a weak filter if one is photographing the infra-red. This prismatic filter proved that the limit reached in the spectrum was due to lack of sensitiveness in the film. On account of the many reflections necessary this filter is quite wasteful of light, so that a filter made of dye stuff will probably always be found more serviceable in the infra-red. But it may be of great use in photographing the ultra-violet, as it will permit the photography of the third and fourth orders. This will allow a more minute study of the solar spectrum than has ever been made. It will also be possible to obtain standards in the extreme ultra-violet by the coincidence method.

Of the usefulness of infra-red photography there can be no question. Any addition to our knowledge of the spectrum of any source is of interest, if not for the moment of great importance. The observation of series lines of great wave-length is of prime importance in connection with the study of the nature of the radiant source. In astronomy the time is at hand when celestial spectra may be photographed with sufficient dispersion to show some of the sharp telluric lines and thus give a check on velocities spectrographically determined. No doubt spectrograms of the region 6000 A–7200 A would give at least rough values for the radial velocity, the water-vapor band playing the rôle of comparison spectrum. There are several spectroscopes of small dispersion in operation throughout the world which should be able to photograph the spectrum of a second-magnitude star as far as 8000 A. With an instrument having a single glass prism of sixty degrees angle it should be possible to reach 7200 A. The study of the solar spectrum with high dispersion ($A = 0.5^{mm}$) is now possible as far as 9200 A, and perhaps much farther. (It is not possible to observe the Sun in the Physicalischer Institut here in Bonn.) This study must surely yield interesting results. The bands of several compounds are exceedingly intense in the infra-red and their detection in the spectrum of the Sun, particularly in the spectra of sun-spots, seems highly probable. Finally, our knowledge of the water-vapor content of the upper air rests largely on the results of spectroscopic research. As is the case with most telluric lines, the water-vapor bands lie to the red of the region of sensitiveness of the ordinary photographic plate. For this reason meteorologists have a great interest in the development of infra-red photography.

The subject of red-sensitive plates is under investigation in many quarters and we may confidently look for the improvement of old methods and the introduction of new ones. If not in the next year, then almost certainly in the next decade, the problem will be solved to such an extent that the spectrum from 8000 A to 20,000 A will be as easily photographed as the green, and the great rain band will be observed photographically as a matter of routine.